# AUV Navigation and Platform Development

Samuel M. Smith.*

P. Edgar An

*Ocean Engineering Dept., SeaTech, Florida Atlantic University,
101 N. Beach Rd., Dania FL, 33004.
(tel) 954-924-7232  (fax) 954-924-7233 (email) smith@oe.fau.edu (web) www.oe.fau.edu

## 1    LONG-TERM GOALS

.To effectively carry out the mine-reconnaissance and hydrographic experiments with multiple AUVs, they must be able to self-localize accurately in an unknown or partially known environment such that relevant targets and adverse oceanographic conditions can be spatio-temporally characterized precisely. We wish to address the implementation and enhancement issues associated with applying advanced processing algorithms to a low-cost computing platform to provide a synergistic navigation solution given the size, power and cost constraints of small AUVs.

To refine the next generation ultra modular mini AUV platforms for current and future sensor development and deployment on a portable commercializible platform. This will reduce costs and foster the innovative development and spread of associated sensor systems and applications.

## 2    OBJECTIVES

The primary goal of this project is to continue development and refinement of our next generation mini ultra-modular AUVs and provide enhanced capabilities in navigation and positioning. This particular project is aimed at improvements to low cost navigation systems using COTS equipment and extended Kalman filtering with sensor bias learning and compensation. Other related work includes the study of autonomous fault detection and compensation, as well as sea state learning for use in motion planning and oceanographic survey.

One important design characteristic of these miniaturized AUVs is their enhanced modularity and field-reconfigurability, as compared to the existing Ocean Explorer series. With this added capability, we are given an additional freedom to dynamically reconfigure the baseline of these mini AUVs for optimizing hydrodynamic loading, sensor interferences, and the stinger location for docking. We wish to further quantify the performance of the mini AUVs in relation to navigation, control, hovering, and communication, and compare them with those of the Ocean Explorers.

## 3    APPROACH

### 3.1    Mini AUV

As electronics and computer technology progress the size and power consumption of underwater sensor, computing, and navigation systems is decreasing. Moreover the major cost in AUV operations is the cost of the support vessel and personnel which is primarily driven by the size and weight of the AUVs. Drag and power consumption are also directly related to AUV size. Reliable operation requires careful attention to maintenance and integration overhead. In response to these trends and relations, we have designed and built a new ultra modular mini AUV with pressure vessels molded out of plastic. Many of the sensor systems developed by FAU, USF and other collab-

| | Report Documentation Page | | *Form Approved* *OMB No. 0704-0188* |
|---|---|---|---|

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| 1. REPORT DATE **30 SEP 1999** | 2. REPORT TYPE | 3. DATES COVERED **00-00-1999 to 00-00-1999** |
|---|---|---|

| 4. TITLE AND SUBTITLE **AUV Navigation and Platform Development** | 5a. CONTRACT NUMBER |
|---|---|
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Atlantic University,Department of Ocean Engineering, Sea Tech,101 N. Beach Rd,Dania,Fl,33004** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
|---|---|

| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
|---|---|
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT **unclassified** | b. ABSTRACT **unclassified** | c. THIS PAGE **unclassified** | **Same as Report (SAR)** | **6** | |

orators are small enough to fit on this new platform. The mini AUV is a more cost effective way to deploy these sensors and is more amenable to operation by the scientists themselves without requiring as much support from FAU.



*Figure 3.2* AUV on chase boat.



*Figure 3.1* Minimal configuration Mini AVU

The new mini AUV has been designed to minimize integration, reconfiguration, maintenance and operations costs. Structurally the Mini AUV is composed of modular molded plastic sections of various lengths between 6 and 24 inches. These sections can serve either as dry pressure vessels or as faired flooded or pressure compensated sections. The plastic is a high strength micro glass fiber reinforced resin called Ultem. It has comparable strength to aluminum but is lighter weight. By using plastic the maintenance problems of corrosion and ground faults are minimized. A unique cabling system that runs along faired channels on the outside of the sections allows easy interchange of the order of the sections without having to open or rewire any of the sections. This design uses the same LONTalk based distributed control system as the OEX so only one power and network cable is needed for most of the sensors and actuators and likewise many of the elec-

tronic components are easily transferred to the new design.

## 3.2 Navigation

The FAU and NPS investigators have, using one of the FAU Ocean Explorer AUVs, conducted a series of survey runs designed to characterize the errors produced in navigation with dead reckoning. The system employs a triaxial magnetometer for compass heading, an Acoustic Doppler Velocity Log to measure speed over the ground and water column. In theory, with perfect measurement, the velocities rotated into navigation coordinates may be integrated on-line to provide the vehicle with knowledge of its position. Experimental results, however, indicated that the heading bias, based on low-cost COTS magnetometer, is the most dominant source of error found in inertial navigation. With sensor errors these systems degrade and to achieve a one percent of distance travelled error compass heading should be accurate to within a degree. The errors in compass heading are critical to precision in navigation of these small vehicles, so there is a need to both compensate for these errors before missions, and to on-line fuse independent position measurements, such as DGPS / LBL / USBL sensors.

# 4 WORK COMPLETED

## 4.1 Mini AUV

The OEX software was successfully ported to the PC-104+ QNX OS on the mini. An improved version of the LonTalk driver software has been developed and self installation is under advanced development.

The mini pressure vessel manufacture and tuning was completed. The vehicle has received a rating of 200 meters. This is a limitation of the non-fixed end cap. The main vessel rating exceeds 300 meters. A bare bones version of the mini was constructed and several at sea tests conducted this summer. The final design of the fully integrated mini with a complete basic sensor suite has been completed and built. At sea tests are underway. A cancellation by Ultralife of their Lithium Ion batteries require a complete rework of the battery systems design causing significant delays for the battery system. The stepper/servo motor fin section has been completed as well. This minimizes moving parts. The thruster sections have been designed and are under construction. A diagram of the completed packaged main computer, navigation, and battery sections is shown below. A highly integrated LonTalk control module was developed called the High Performance Standard Node. A full blown version of the base mini showing thrusters is given below.
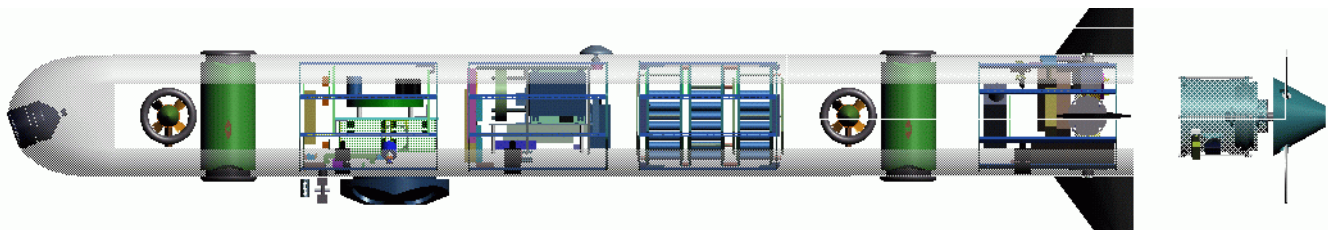


*Figure 4.2* Mini AUV with thrusters.

## 4.2 INS

Prior work included compass bias characterization using a KVH fiber-optic single-axis gyro (FOG) as a short-term angular reference, and the development of an extended Kalman filter which
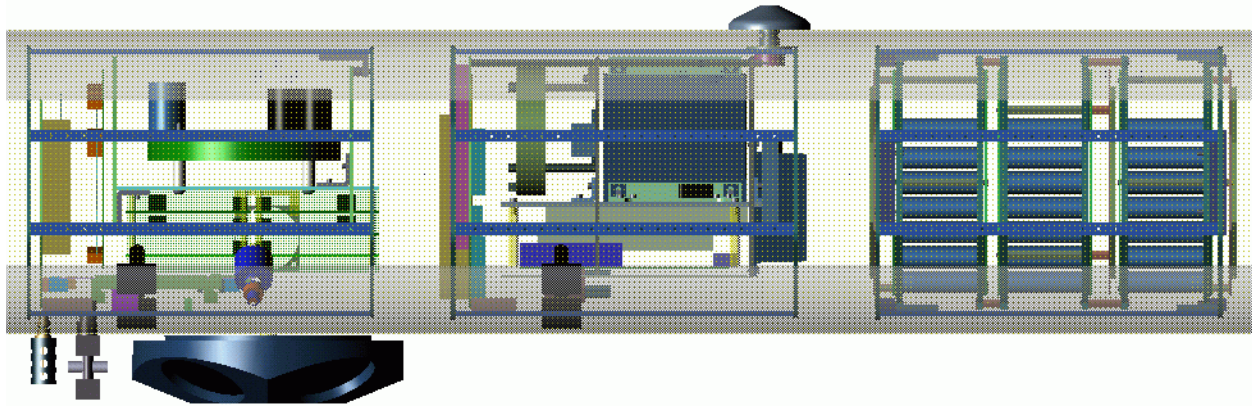
*Figure 4.1*      In order from left to right: Main computer section including DVL, CTD, and Health Board; Navigation Module including FOG gyros, acosoustic modem; Battery section showing NiMh batteries..

identifies the residual heading bias in a compensated system. Current findings, however, suggest that the residual bias is non-stationary. That is, it varies with true heading in a more or less periodic fashion. Rigorous characterization of the FOGs suggest that the overall dynamic bias can be as large as 15 deg / hour even after compensation. This is believed to be caused by the inaccuracy of the internal temperature sensor. This year, we have procured an inertial measurement unit (HG1700-AG25) made by Honeywell, and major effort was on the design and implementation of an inertial navigation unit using HG1700-AG25.

The hardware design for the INS system is twofold: selection of adequate electronics needed to perform the communication and computing tasks, and mechanical packaging of the INS module into a MiniAUV in a convenient manner. So far the mechanical design has not been fully built, whereas the electronics configuration is almost finalized. Several boards are required to complete the different tasks of the INS system. These tasks include powering the instruments and the electronics, reading the instruments' outputs, computing the instruments' corrections and the Kalman filter algorithm, and finally communicating with the vehicle's shared memory. So far, a power and communications interface board for the Honeywell unit has been designed, built and tested. This board requires a 48 VDC input voltage, and converts the RS-422 output from the IMU into RS-232 format. The approach in the selection of the boards focused on minimizing the number of parts, limiting the power consumption, while allowing future upgrades. The main processor currently in use for the INS system is a PC/104 CoreModule CM2-4Di, 100/133MHz, from Ampro Computers. However, a second, more recent and higher performance board, the CoreModule CM3-P5e, is also on order, and will be used either for the second INS module, or if the 4Dxi proves to be insufficiently powerful.

Design and implementation of the navigation and interface software is a another major effort of the INS implementation. The INS computer runs on a PC-104 platform with QNX as its real-time operating system. It was chosen because of its real-time capabilities, and the parallel work done on the host computer within the mini-AUVs. Initial development of the software was made on a littleBoard P5i, and the final software will be downloaded to the PC/104 processor

The remaining task, which has not been performed, is to characterize the filter and navigation performance. To accomplish this task, the system must be mechanically assembled together on a

bench test, data from the gyroscopes, GPS, compass and DVL acquired (or at least simulated), and some kind of motion must be given to the unit. Based on the output of the system, the parameters of the filter will be tuned to provide better and faster convergence behaviors. This task will be carried out once the mechanical packaging is complete, which is approximately November of 1999. We expect that the characterization performance will take about 1 to 2 months to complete.

## 5 RESULTS

The ultra modular plastic mini AUV sets a new innovative standard for AUV design. The new INS will undergo testing by the end of the year

## 6 IMPACT/APPLICATIONS

It is expected that the new mini AUV will be commercialized next year and serve as a key participant in future shallow water MCM research.

Navigation of underwater platforms is critical to survey and mapping work. Low cost systems are also essential to the Navy's future. While precision navigation may be solved for large submarines, low cost units for small AUVs will have to rely on less accurate sensors and ways of fusing information from a variety of sources to maximize the achievable accuracy will be important.

## 7 TRANSITIONS

The current plan is to have further development work on the Mini be done outside the university.

This work transition into Ocean Sampling Systems using low cost AUVs, and to Models for VSW Minefield Simulation technology.

## 8 RELATED PROJECTS

Coordination of Experiments Using AUVs at the SFTF, ONR.

AUV Hydrodynamics in Shallow Water during Adverse Weather Conditions, ONR.

Acoustic Communications with AUVs and AOSN Development

AUV Navigation and Platform Development

Remote Sampling and Survey of Shallow Water Using AUVs w/application to Mine Reconnaissance and operations support for experiments using the FAU AUVs.

Sampling and Survey with AUVs in Adverse Weather Conditions

ONR MURI on Nonlinear Control

ONR funded work in Fault detection and Compensation

ONR work funding the Modeling and Simulation of Multi Robot Systems performance in UXO clearance.

# 9 PUBLICATIONS

P.E. An , M. Dhanak, N. shay, J. Van Leer, Sam Smith, Coastal Oceanography Using a Small AUV, submitted to Journal of Atmospheric and Oceanic Technology, Sept 1998

A. Healey, P.E. An, S.M. Smith, "Multi-Sensor Asynchronous Extended Kalman Filtering for AUV Navigation, Submitted to the IEEE Transactions on Oceanic Engineering.

GS Rae, D. Kronen, S. Smith, FAU Technical Report, Docking Navigation Experiment. September 1999

S. Smith, L. Marquis, S Snowden, FAU Technical Report, MCM Experiment Dec 1998.

S. Smith, L. Marquis, S. Snowden. FAU Technical Report, AUV Fest 1998,

S. Smith, S. Snowden, FAU Technical Report, ACOMS Hawaii Experiment

J. Jalbert, FAU Technical Report, CoBop Experiment

J. Jalbert, FAU Technical Report, 4D Current Experiment

J. Jalbert, FAU Technical Report, Adverse Weather Experiment.

Feijun Song, Samuel Smith, Charbel Rizk, "A General Cell State Space Based TS Type Fuzzy Logic Controller Automatic Rule Extractions and Parameter Optimization Algorithm". IEEE Industrial Electronics Conference, IECON 99 San Jose CA November 29 - December 3rd 1999.

Feijun Song, Samuel Smith, Charbel Rizk, "A Fuzzy Logic Controller Design Methodology for 4D Systems with Optimal Global Performance Using Enhanced Cell State Space Based Best Estimate Directed Search Method",1999 IEEE International Conference on Systems Man and Cybernetics , Tokyo Japan, October 12-15, 1999

Feijun Song, Samuel Smith, Charbel Rizk, "Reducing Memory Requirement of Cell State Space Based Fuzzy Logic Controller Design Approaches Using K-d Trees" 1999 IEEE International Conference on Systems Man and Cybernetics , Tokyo Japan, October 12-15, 1999

Xiaohong Yuan, K. ganesan, Matthew Evett, Samuel M. Smith, "Providing Real-time Data Trajectory Access in Autonomous Underwater Vehicles", Proceeding IEEE Oceans 99 Conference, September 13-16, 1999, Seattle WA

Xiaohong Yuan, K. Ganesan, Scott Snowden, Samuel M. Smith, Matthew Evett, "Mission Command Macros For Autonomous Underwater Vehicles, Proceeding IEEE Oceans 99 Conference, September 13-16, 1999, Seattle WA

Alexandre Delarue, Samuel Smith, Edgar An, "AUV Data Processing and Visualization Using GIS and Internet Techniques", Proceeding IEEE Oceans 99 Conference, September 13-16, 1999, Seattle WA

M. Dhanak, E. An, K. Holappa, S. Smith, "Using Small AUVs for Oceanographic Measurements" Proceeding IEEE Oceans 99 Conference, September 13-16, 1999, Seattle WA

G. Grenon, E. An, S. Smith, "Enhancement of the Inertial Navigation System" Proceeding IEEE Oceans 99 Conference, September 13-16, 1999, Seattle WA

D. Mallinson, D. Naar, A. Hine, S. Smith, S. Schock, d. Wilson and G. Gelfenbaum, "Seafloor Mapping and Target Identification Using AUVs: Applied AUV Experiments, UUST 99 Durham NH August 23-25, 1999.

Feijun Song, Samuel Smith, Charbel Rizk, "Optimized Fuzzy Logic Controller Design for 4D Systems Using Cell State Space Technique with Reduced Mapping Error", IEEE Conference On Fuzzy Systems, FUZZ-IEEE 99 Seoul Korea, August 23- 25 1999.

S.M. Smith, D. Kronen, R. Dunn, J. Whitney, J. Frankenfield, E. An, T. Pantelakis, A. Burns, E. Hetzig, "An Ultra Modular Plastic Mini AUV Platform for VSW Mine Reconnaissance". SPIE Aerosense, 1999, Orlando Florida April 5-9, 1999.

S.M. Smith, P.E. An, R. Christiansen, J. Kloske, S. Snowden, D. Kronen, L. Marquis. "Results of an Experiment Using AUVs for Shallow Water Mine Reconnaissance, SPIE Aerosense, 1999, Orlando Florida April 5-9, 1999.

SV, UUVs OE 98 Sept. 1998 Southhampton England